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NITROGEN TRANSFORMATIONS IN COMPOSTS PRODUCED FROM MUNICIPAL SOLID WASTES

PRZEMIANY ZWIĄZKÓW AZOTU W KOMPOSTACH PRODUKOWANYCH ZE STAŁYCH ODPADÓW MIEJSKICH

Abstract: The aim of the research was to estimate the direction and intensity of nitrogen transformations in composts produced from municipal solid wastes (MSW), including time, composting parameters and composting technology. Objects of studies were composts at different maturity stages, produced according to two different technologies: MUT-DANO in Katowice and KKO-100 in Zielona Gora. In collected samples the following determinations were performed: temperature, humidity, pH in KCl, C_{org} – total organic carbon, N_t – total nitrogen, N_w – water soluble nitrogen, $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ in water extracts (compost to water ratio 1:10). Obtained results show that during composting of MSW the amounts of N_t and $N\text{-}NO_3^-$ increased while those of N_w and $N\text{-}NH_4^+$ decreased. Intensity of those changes was statistically confirmed and correlated with composting conditions. Prolonged anaerobic conditions in material from Katowice inhibited nitrification processes, which was confirmed by higher $N\text{-}NH_4^+/N\text{-}NO_3^-$ ratio. To take into consideration the value of this rate, compost from Katowice did not reach maturity even after 180 days of composting.

Keywords: composting of municipal solid wastes, nitrogen transformations

Nitrogen transformations in the course of the process of composting take place as a result of biological processes that include ammonification, nitrification and denitrification. The resultant of those processes are changes in quantity and quality of that macrocomponent [1]. Due to the fundamental importance of nitrogen in the determination of fertiliser quality of composts, numerous studies have been performed to date on nitrogen transformations in the various phases of compost maturity and for various composting conditions [2–4]. Results obtained so far indicate an increase in total nitrogen with progress of the composting processes. However, taking into account the nature aspect of application of composts, one should consider not only the total levels of their components, but also of forms of those components with various levels of availability.

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In spite of the studies conducted for years within this field, no optimum system of control of nitrogen transformations during composting has been developed. This is most likely due to the extensive variability of the morphological and chemical composition of wastes, which makes the choice of suitable technology difficult, while application of universal solutions not always brings the expected results. Therefore, the objective of this study was to acquire knowledge on the intensity and directions of nitrogen transformations during composting of municipal solid wastes by means of various techniques.

Material and methods

The experimental materials were composts produced of solid municipal wastes according to different technologies, those of MUT-DANO in Katowice and KKO-100 in Zielona Gora. Samples for analyses were taken at intervals of 10–14 days, in different phases of maturation of composts on the prism. A total of 11 samples were collected from the composting plant in Katowice, and 10 samples from that in Zielona Gora. To identify the processes of nitrogen transformation, the following determinations were made: temperature, pH in KCl, current moisture level, C_{org} – organic carbon, with the Tiurin oxidimetric method, N_t – total nitrogen and N_w – water-soluble nitrogen (1:10) with the Kjeldahl method on the Büchi apparatus, content of mineral forms of nitrogen (N_{min}): $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ in water extracts (1:10) using ion-selective electrodes "Elmetron".

The obtained results permitted evaluation of the material under study on the basis of selected chemical indices of compost maturity.

Statistical analysis was performed on the basis of mean values from three replications for each date f analysis, while all the results were used for statistical calculation by means of the "Statistica 7" software.

Results and discussion

Temperature is one of the most important physical criteria for the estimation of compost maturity, and at the same a measurable indicator of the intensity of processes of biotransformation taking place in the course of composting [1, 5, 6]. Its changes in the course of composting are related with the metabolic activity of microorganisms whose succession varies in a dynamic manner depending on the phase of composting. The most important phase of composting is the thermophilic phase, when the temperature of the composted mass reaches 55 ^oC.

In the case of the compost produced in Katowice, the thermophilic phase (with temperature > 55 ^oC) began on the 19th day of composting and ran in 5 cycles, the longest of which lasted 10 days, and the shortest 2 days (Fig. 1). Extended duration of the thermophilic phase and its division into several short parts is a consequence of incorrect care of the prism, and in particular of the neglect – in the initial weeks of composting – of application of stirring and aeration of the composted mass. Reshuffling of the prism was made three times, between days 60 and 65 of composting.

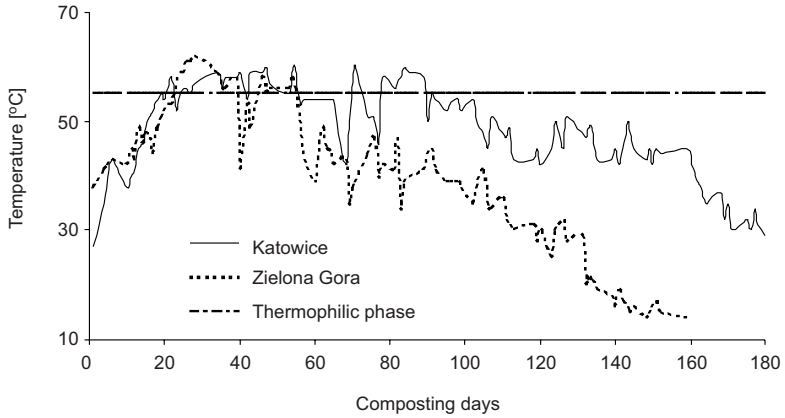

Fig. 1. Changes of the temperature during composting municipal wastes

In the compost produced in Zielona Gora, the thermophilic phase started on the 23rd day of composting and lasted for 16 days (Fig. 1). Two cycles were observed, of 10 and 6 days, respectively. Maximum temperature of 64 ^{o}C was recorded on the 28th day of composting. It should be emphasised that in terms of aeration and stirring the compost prism in Zielona Gora was maintained correctly, those treatments being performed regularly at every 10–20 days.

Based on studies performed earlier [7, 8], the moisture level of composted mass is an important factor determining the growth and functioning of microorganisms responsible for the processes of biotransformation. It is assumed that the most optimal water content in composts is 400–600 mg H_2O kg^{-1}. The results obtained in this study (Fig. 2) show that the moisture level was variable in the time of composting. In both composts it was initially within the optimum range, between 400 and 550 mg H_2O kg^{-1}, but after the start of the thermophilic phase, both in Katowice and in Zielona Gora, there occurred a drop in compost moisture below 400 mg H_2O kg^{-1} (56–70 day of composting). Return

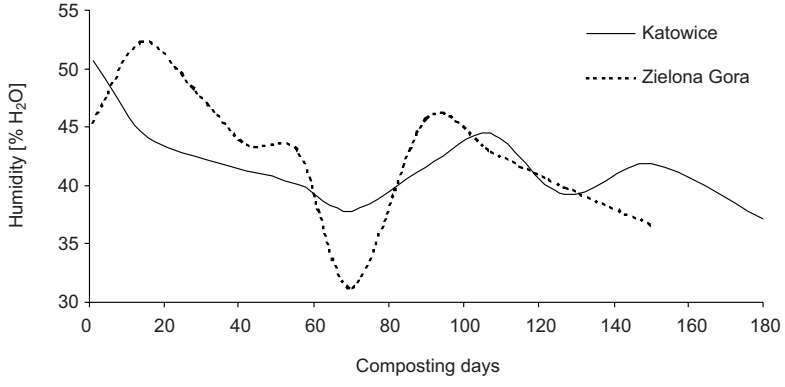

Fig. 2. Changes of composted municipal wastes humidity

to the optimum level in the compost from Katowice took place as a result of a rainfall, while in Zielona Gora artificial supplementary irrigation was applied.

Many studies [1, 3, 4] point out changes in pH that take place in the course of composting. Those result from the varied intensity of biochemical processes during composting, determined primarily by temperature, aeration and moisture level of the maturing compost. The results obtained in this study clearly indicate a relation of the pH values with the changes that take place during the termophilous phase of compost maturation (Fig. 3). In that phase an increase in pH values was observed in both composts under study. This was probably due to intensive release of alkaline cations as a result of processes of mineralisation, especially of large amounts of NH_3 as a result of hydrolysis of proteins. In further phase of composting, with progressing processes of maturation, a distinct lowering of pH was observed, followed by stabilisation of the value of that parameter.

Organic matter contained in solid municipal wastes undergoes continuous transformation in the course of their composting. In the light of earlier studies [5, 6, 9], there

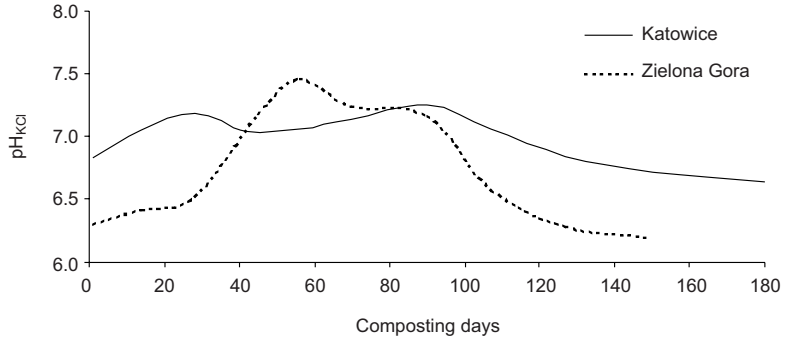

Fig. 3. Changes of pH_{KCl} value in differently matured composts from municipal wastes

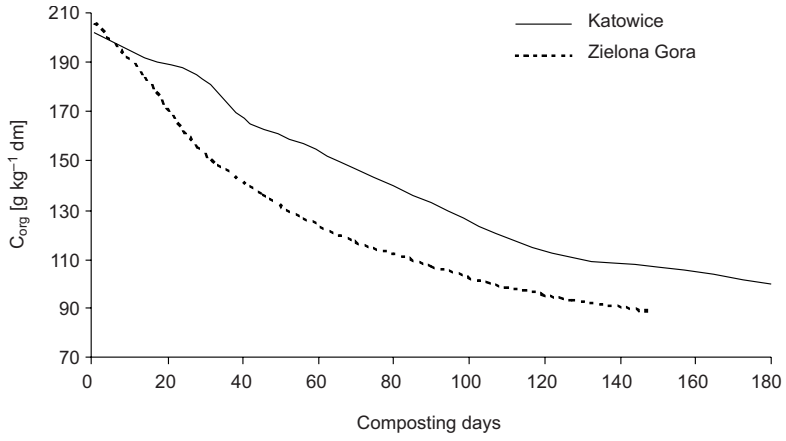

Fig. 4. Changes of C_{org} contents in differently matured composts from municipal wastes

takes place a reduction of the amount of organic matter that may even reach more than 50% of the initial value. Changes in the content of total organic carbon (C_{org}) during composting of solid municipal wastes in Katowice and Zielona Gora indicate that in both cases the loss of carbon exceeded 50% (Fig. 4, Table 1).

In the case of the compost from Zielona Gora, the values obtained and the dynamics of changes in the content of total carbon did not differ significantly from values obtained by other authors [6, 7, 9]. Changes in the content of C_{org} in the compost produced in Katowice ran a somewhat different course. Due to the neglect concerning the correct maintenance of the prism, there was a less pronounced effect of the termophilic phase in the intensity of carbon mineralisation. When composting of wastes proceeds under more anaerobic conditions, the processes of organic matter transformation are notably slowed down.

Table 1

Changes of C_{org} and different forms of nitrogen contents during maturity of composts from municipal wastes

Composting days	C_{org}	N_t	N_w	C_{org}	N_t	N_w
	[g kg^{-1}]		[mg kg^{-1}]	[g kg^{-1}]		[mg kg^{-1}]
	Katowice			Zielona Gora		
1	201.7	6.4	1467.0	205.9	5.7	1433.0
14	192.0	7.7	1367.0	183.9	6.2	1380.0
28	184.9	8.0	1300.0	155.5	6.3	1306.0
42	165.0	8.6	1133.0	135.8	7.9	911.0
56	157.4	8.8	1100.0	126.1	8.2	854.0
70	146.7	9.0	1199.0	116.4	8.4	884.0
90	132.8	9.8	1200.0	106.8	9.2	805.0
107	120.4	12.6	900.0	99.1	11.9	761.0
127	110.4	13.3	800.0	92.8	12.6	667.0
150	107.0	14.1	700.0	87.8	13.4	746.0
180	100.1	14.4	667.0	—	—	—

During composting, changes were observed in the content of nitrogen and its particular forms (Table 1). The highest levels of total nitrogen N_t were observed in the final phase of maturation, when they amounted to 14.4 g kg^{-1} in the compost from Katowice and 13.4 g kg^{-1} in the compost from Zielona Gora. These results are in agreement with those of numerous earlier studies which also revealed an increase in nitrogen content during the later phases of composting.

The different conditions prevailing in the compost prisms under study determined the different runs of the processes of organic matter transformation that were conducive to the formation of water-soluble forms of nitrogen (N_w). In both composts a decrease was observed in the content of water-soluble nitrogen N_w with the progress of their maturation (Table 1). This was probably due to the incorporation of nitrogen in the structures of organic compounds, and of humic acids in particular.

The highest level of the form $N\text{-}NH_4^+$ (773 mg kg^{-1}) was recorded on the 70th day of composting in the material from Katowice, and on the 45th day (737 mg kg^{-1}) in the material from Zielona Gora (Fig. 5). This may be related with intensive processes of hydrolysis of protein substances taking place in the termophilic phase [4, 6, 7, 9].

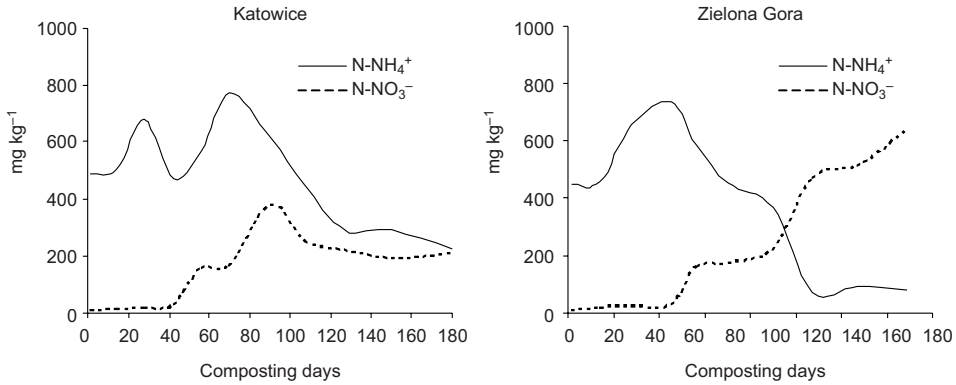

Fig. 5. Changes of mineral, water soluble nitrogen forms contents during maturity of composts from municipal wastes

The lowest levels of that form of nitrogen, 227 mg kg^{-1} in the compost from Katowice and 78 mg kg^{-1} in that from Zielona Gora (Fig. 5), were recorded in the final phase of composting. The lowering in the content of the ammonium form of nitrogen was more pronounced in the compost from Zielona Gora, which could have been determined by more favourable aeration conditions.

The different conditions of composting were also reflected in the dynamics of formation of the nitrate form of nitrogen. In both composts there was an increasing trend of $N\text{-}NO_3^-$ – from 8 to 634 mg kg^{-1} in Zielona Gora and from 7 to 210 mg kg^{-1} in Katowice. The notably lower level of that form of nitrogen in the compost from Katowice indicates an effect of insufficient aeration of that material on the quality of compost produced. Extended anaerobic periods inhibited the processes of nitrification in the compost from Katowice, which was manifested in a decrease in the level of the form $N\text{-}NO_3^-$ with relation to $N\text{-}NH_4^+$ (Fig. 5). These results are evidence of less favourable direction of transformation of nitrogen compounds and at the same indicate incomplete maturity of the compost [1, 3, 7].

Based on the results obtained, an estimation of the maturity of the composts was performed (Table 2) taking into account the following chemical indices [3]:

– ratio of organic carbon to total nitrogen – C_{org}/N_t,

– oxidation index of mineral forms of nitrogen – $(N\text{-}NH_4^+/N\text{-}NO_3^-)$,

– ratio of water-soluble nitrogen to total nitrogen – $(N_w/N_t) \cdot 100$,

– index of nitrogen mineralisation in water extract – $(N_{min}/N_w) \cdot 100$.

When estimating composts based on the above indices, attention should be paid to the time of composting, after which a given parameter attains relative stabilisation.

Table 2

Changes of chemical compost maturity indices value during composting of municipal wastes

Composting days	C_{org}/N_t	$(N_w/N_t) \cdot 100$	$(N_{min}/N_w) \cdot 100$	$N\text{-}NH_4^+/N\text{-}NO_3^-$
Katowice				
1	31.7	23.0	34.1	70.4
14	24.9	17.8	38.0	31.5
28	23.0	16.2	53.8	34.0
42	19.3	13.2	44.1	18.2
56	17.8	12.5	65.8	3.6
70	16.2	13.3	78.3	4.7
90	13.5	12.2	82.8	1.6
107	9.6	7.1	77.4	1.8
127	8.3	6.0	64.0	1.3
150	7.6	5.0	69.0	1.5
180	7.0	4.6	65.5	1.1
Zielona Gora				
1	36.1	25.1	31.6	55.6
14	29.7	22.3	34.3	25.3
28	24.7	20.8	51.7	29.7
45	17.2	11.5	84.0	26.3
56	15.5	10.5	87.5	3.6
70	13.9	10.6	70.6	2.6
90	11.7	8.8	72.9	1.7
107	8.3	6.4	71.2	0.2
127	7.4	5.3	90.6	0.2
149	6.6	5.6	95.4	0.1

One of the most frequently used parameters defining the degree of maturity of composts is the ratio of total organic carbon to total nitrogen, C_{org}/N_t. It is accepted that mature composts should have a stabilised value of that index at the level of ca 10. The study clearly demonstrated a reduction in the value of that ratio with progressing processes of compost maturation (Table 2). This results primarily from the notable loss of carbon in the process of mineralisation, and from the incorporation of nitrogen into structures of humus compounds formed in the process of humification. Analysing the run of changes in the values of that index during composting one can demonstrate that in both composts distinct stabilisation was observed after about 90 days, with a slight but continuing decreasing trend.

Indices based on nitrogen transformations can be another important group of indicators of compost maturity. One of the most important indices is the ratio $N\text{-}NH_4^+/N\text{-}NO_3^-$ which defines the rate of transformation of the ammonium form of nitrogen into the nitrate form, with relation to the conditions in the prism. It is assumed that a value of the ratio of $N\text{-}NH_4^+/N\text{-}NO_3^-$ close to 1 indicates the beginning of stabilisation of processes related to nitrogen transformation, characteristic for mature compost. In the analysed composts (Table 2), distinct stabilisation of that index was

observed in the case of Zielona Gora after 107 days of composting, when its value was less than 0.2. Modifications applied in the maintenance of the prism in Katowice resulted in slower rate of transformation of nitrogen compounds, which was evidenced by a higher value of that index (above 1.0) after 180 days of composting. Based on the index $N\text{-}NH_4^+/N\text{-}NO_3^-$, the compost produced in Katowice did not reach full maturity even after such a long time of composting.

Another index defining the maturity of composts on the basis of nitrogen transformations is the percentage share of its water-soluble forms in relation to the total nitrogen content $(N_w/N_t) \cdot 100$. In both composts under study stabilisation of this index was observed after 90–107 days of composting, and its value oscillated within the range of 8.8–5.3 % in Zielona Gora, and 7.1–4.6 % in Katowice (Table 2).

Analyses of the composts from Katowice and Zielona Gora showed changes in the value of the index of mineralisation of nitrogen extracted in water extract $(N_{min}/N_w) \cdot 100$. In both composts (Table 2) an increase was observed in the value of that index with the passage of time of composting, with stabilisation after 127 days. The less favourable aerobic conditions and the extended thermophilic phase during composting in Katowice resulted in a certain modification of the values of the index.

Based on the calculated coefficients of correlation between the composting conditions (time, temperature and moisture) and the amount of organic carbon and nitrogen forms, matrices of correlation were created (Table 3). In both composts significant negative correlation was found between the content of C_{org} and temperature and time of composting, and significant positive correlation between organic carbon level and moisture. The parameter that distinctly differentiated nitrogen transformations in the composts was temperature. The levels of N_t and $N\text{-}NO_3^-$ displayed significant positive correlation with composting time and temperature, while the amounts of water-soluble nitrogen N_w were significantly negatively correlated with those parameters. In the case of the compost from Zielona Gora, significant negative correlation was found between the run of composting temperature and time and the amount for created forms $N\text{-}NH_4^+$, while in the compost from Katowice temperature did not have any significant effect on the level of those forms.

Table 3

Correlation coefficients between composting parameters and organic carbon and different forms of nitrogen

Parameters	C_{org}	N_t	N_w	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$
Katowice (N = 33, $p < 0.05$)					
Composting time	–0.87	0.92	–0.76	–0.64	0.56
Temperature	–0.97	0.75	–0.79	–0.33*	0.62
Humidity	0.82	–0.50	0.73	0.09*	–0.27*
Zielona Gora (N = 30, $p < 0.05$)					
Composting time	–0.76	0.93	–0.88	–0.78	0.96
Temperature	–0.94	0.58	–0.74	–0.49	0.54
Humidity	0.62	–0.52	0.63	0.34*	–0.53

* Non – significant correlation.

Significant positive correlation between moisture and content of N_w, determined in both composts, indicates an increase in the content of that form of nitrogen with moisture. Negative correlation between moisture and the content of N_t in both composts may indicate unfavourable effect of increased moisture on nitrogen content in the compost. Also noteworthy is the discovery of significant negative correlation between moisture and the content of $N\text{-}NO_3^-$ that occurred in the compost from Zielona Gora. This relationship indicates that increase in moisture may result in decrease in the content of that form of nitrogen in composted material. In the compost from Katowice no significant correlation was found between moisture and the content of $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$. This may be grounds for conclusion that composting technology may have a strong effect on nitrogen forms occurring in composts.

Conclusions

1. During composting of solid municipal wastes a decrease was observed in the content of organic carbon, an increase in the total content of nitrogen, and quantitative changes in the levels of particular forms of nitrogen.

2. The rate of nitrogen transformations depended primarily on compost moisture, on the time of composting, and on the composting technology applied.

3. During compost maturation there was an increase in the content of $N\text{-}NO_3^-$, and the intensity of that process was inhibited under less favourable aerobic conditions.

4. The study shows that the index $N\text{-}NH_4^+/N\text{-}NO_3^-$ provides good representation of nitrogen transformations in the course of composting and can be applied for the estimation of compost maturity.

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PRZEMIANY ZWIĄZKÓW AZOTU W KOMPOSTACH PRODUKOWANYCH ZE STAŁYCH ODPADÓW MIEJSKICH

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Abstrakt: Celem przeprowadzonych badań było określenie kierunków i intensywności procesów transformacji azotu w kompostach produkowanych z odpadów miejskich z uwzględnieniem czasu i warunków

kompostowania oraz zastosowanej technologii. Badaniami objęto komposty wytwarzane z odpadów miejskich według odmiennych technologii: MUT-DANO w Katowicach i KKO-100 w Zielonej Górze. W celu poznania warunków procesów przemian azotu, wykonano oznaczenia: temperatury, wilgotności aktualnej, pH w KCl, C_{org} – węgla organicznego, N_{og} – azotu ogółem, N_w – azotu wodnorozpuszczalnego (kompost: woda jak 1:10), $N\text{-}NH_4^+$ i $N\text{-}NO_3^-$ w ekstraktach wodnych (1:10). Wyniki badań wykazały, iż w czasie kompostowania odpadów miejskich następuje wzrost zawartości N_{og} i $N\text{-}NO_3^-$ oraz obniżenie zawartości N_w i $N\text{-}NH_4^+$. Intensywność tych zmian, zależała od warunków kompostowania. Przedłużone warunki beztlenowe w materiale kompostowanym w Katowicach, hamowały procesy nitryfikacji, co wyrażało się zmniejszeniem ilości formy $N\text{-}NO_3^-$ w stosunku do $N\text{-}NH_4^+$. Biorąc pod uwagę indeks $N\text{-}NH_4^+/N\text{-}NO_3^-$, kompost produkowany w Katowicach nie osiągnął stanu pełnej dojrzałości nawet po 180 dniach kompostowania.

Słowa kluczowe: kompostowanie odpadów miejskich, transformacja azotu